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# Feasibility study of harnessing wind energy for turbine installation in province of Yazd in Iran

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ABSTRACT

This paper analyses the wind speed of some major cities in province of Yazd which is located in central part of Iran. Also, the feasibility study of implementing wind turbines to take advantage of wind power is reviewed and then the subject of wind speed and wind potential at different stations is considered. This paper utilized wind speed data over a period of almost 13 years between 1992 and 2005 from 11 stations, to assess the wind power potential at these sites. In this paper, the hourly measured wind speed data at 10 m, 20 m and 40 m height for Yazd province have been statically analyzed to determine the potential of wind power generation. Extrapolation of the 10 m data, using the Power Law, has been used to determine the wind data at heights of 20 m and 40 m. The results showed that most of the stations have annual average wind speed of less than 4.5 m/s which is considered as unacceptable for installation of the wind turbines. City of Herat has higher wind energy potential with annual wind speed average of 5.05 m/s and 6.86 m/s, respectively, at height of 10 m and 40 m above ground level (AGL). This site is a good candidate for remote area wind energy applications. But some more information is required, because the collected data for Herat is only for 2004. Cities of Aghda with 3.96 m/s, Gariz with 3.95 m/s, and Maybod with 3.83 m/s annual wind speed average at height of 10 m above ground level are also able to harness wind by installing small wind turbines. The Tabas and Bafgh sites wind speed data indicated that the two sites have lower annual wind speed averages between 1.56 m/s and 2.22 m/s at 10 m height. The monthly and annual wind speeds at different heights have been studied to ensure optimum selection of wind turbine installation for different stations in Yazd.



**Contents**



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## 1. Introduction

Throughout history, people have harnessed the wind in many ways. Later, people built windmills to grind their grain. Windmills originated in Persia, now Iran, during the A.D. 600s. These early windmills looked like large paddle wheels. These devices used wind energy to grind grain. In Iran due to windy regions, wind mills had been designed and constructed about 200 years before Christ and now a proper path for increasing wind turbine exploitation is provided. Other uses were then developed for windmills such as a pump to lift water from a well. Today, modern devices called wind turbines use wind energy to drive electric power generators. Wind power was first used to generate electric power in Denmark in the 1890s. By the 1990s, there were about 25,000 wind turbines operating in the world. Iran is one of the countries which have recently paid a great attention to install and also build wind turbines. Power wind generators can be a proper replacement for fossil fuel and is one of the cleanest methods of producing electricity. So far Iran has made some initial progress towards promoting wind energy [1]. The combustion of fossil fuels causes serious environmental pollution, therefore it is important to explore the opportunities for clean renewable energy for long-term energy supply in Yazd. It goes without saying that as the world population increases, the demand for other sources of energies increases; therefore the issue of a gradual replacement of fossil fuels with other renewable energy sources like wind is of major consideration for many countries like Iran. There are many different sources of renewable energy (RES) in Yazd, but wind and solar energies are more available and accessible than other kinds. Nowadays, the rapidly increasing demand for electrical energy and the high restriction on pollution levels have led to an increasing interest in large-scale utilization of renewable energies like wind across many countries like Iran.

The growing environmental concern of air quality around the world has created a move to green sources of energy such as wind and solar which provide a pollution-free electricity. Wind is plentiful source available in the nature which could be utilized by mechanically converting wind power to electrical energy using wind turbine. In the last decade, the wind power potential has been studied in many countries world-wide [2–4]. Above all, the skyline is dominated by fantastic mud brick towers (wind catchers or wind tower), giving the city an incredible urban aesthetic. This architectural language repeats itself through most of the ancient cities of the Middle East [5]. People in Yazd province have tried very hard to harness wind energy since many centuries ago, and there are still many wind catchers which harness wind energy for cooling the rooms in summer time.

Recent environmental constraints and new secure technologies have enforced the development of comprehensive programmes for renewable energy. Wind energy is one of the most promising solutions, especially considering its technological advancements and its growth over the past years [6].

It is known that the supplies of fossil fuels are limited and their utilization as energy sources causes environmental degradation due to incomplete combustion when used as energy source, in addition to this as the world population increases the demand for energy sources increases, therefore the issue of a gradual replacement of fossil fuels with renewable energy sources is of major consideration for most countries: Iran Bing located in Asian Middle East enjoys a great potential for producing some 6500 MW of electricity with wind energy [7].

Energy is an essential ingredient of socio-economic development and economic growth. Renewable energy sources like wind energy is indigenous and can help in reducing the dependency on fossil fuels. Wind is the indirect form of solar energy and is always being replenished by the sun. Wind is caused by differential heating of the earth's surface by the sun. It has been estimated that roughly 10 million MW of energy are continuously available in the earth's wind. Wind energy provides a variable and environmental friendly option and national energy security at a time when decreasing global reserves of fossil fuels threatens the long-term sustainability of global economy [8].

Since the scientists and researchers believe the fossil fuel will be scarce at the turn of the 21st century, and the oil reserves would not last for few decades, they find it necessary to study and investigate into the use of ever-lasting or renewable source of energy like wind, the sun; biogas and other sources by the time the energy crisis arrives [9,10].

On the other hand, this country situated in Middle East Asia is rich in fossil fuel supplies such as oil, gas, etc. which make up the basis of its national economy and taking into account the population growth rate energy consumption is quite substantial which could possibly cut down the export rates of fossil fuels. Utilization of renewable energy sources in Iran began a decade ago and it is still in its initial stages of development [7].

It is quite clear how the transformation system of the fossil fuel like thermal plants depends on the energy – producing raw material for instance oil or gas. In future, all oil reserves will run out, or the oil-drilling would not be economical by using the existing methods. One of the basic infrastructural activities is to provide the people living in villages with the energy needed for the domestic uses like heating, lighting as well as water pumping for agricultural purposes. In most cases the isolation of rural places or their long distance distribution to the energy-supply system makes the project improbable and imposes heavy cost [9,10]. It is also necessary for people living in cities to use renewable sources of energies like wind.

On the other hand, since there is an endless cycle of renewable sources such as the wind and the sun all over the country there is an urgent need to use the mentioned sources of energies. The first step to study the feasibility of using the wind energy is to analyze the data from past based upon the wind speed at different elevations. We have studied the feasibility of using the wind in the different areas of Yazd province and compared it with the other acceptable sources by analyzing the speed of the winds and its potentials in past 15 years [9,10].

## 2. General information about province of Yazd

Yazd is the capital of Yazd province in Iran, ‘‘the second most ancient and historic city in the world’’ and a centre of Zoroastrian culture. The city is located some 175 miles southeast of Isfahan. In 2005 it had an estimated population of 433,836 people [12,50] In 2006 it had an estimated population of 505,037 [11,12]. Because of generations of adaptations to its desert surroundings, Yazd is an architecturally unique city. Yazd with the area of 131,551 km$^2$ is situated at an oasis where the Dasht-e Kavir desert and the Dasht-e Lut desert meet, the city is sometimes called ‘‘the bride of the Kavir’’ because of its location, in a valley between Shir Kuh, the tallest mountain in the region at 4075 m above sea level, and Kharaneq. The city itself is located at 1203 m above sea level, and covers 16,000 km$^2$ [12].

Located in the center of Iranian plateau, Yazd province accounts for 6.3% of the whole area of Iran. It borders Fars, Khorasan and Semnan in the north, Khorasan, Kerman in the east, Kerman and Fars in the south, Fars and Isfahan in the west. Yazd is located at the northern latitude of 29–35 and the eastern longitude of 52–58.

**Table 1**
Various Yazd districts.

| District | Area | Population | Cities | Villages |
|---|---|---|---|---|
| Abarkouh | 5941 | 40000 | 2 | 4 |
| Ardakan | 6717 | 70000 | 2 | 5 |
| Bafgh | 15298 | 41000 | 2 | 6 |
| Khatam | 7931 | 32000 | 2 | 4 |
| Mehriz | 6717 | 74000 | 1 | 5 |
| Sadough | 5486 | 26300 | 3 | 3 |
| Tabas | 57337 | 63400 | 2 | 8 |
| Taft | 5948 | 560000 | 2 | 10 |
| Yazd | 2397 | 389000 | 4 | 4 |

Yazd borders the central kavirs, besides there exist salt deserts which act as the drainage system in the plains. The area of Yazd is mostly desert. According to the administrative division rules, the Yazd province is divided into 10 districts; each includes at least one town and a number of villages. These districts are: Abarkouh, Ardakan, Bafgh, Khatam, Maybod, Mehriz, Tabas, Sadough, Taft, and Yazd [12] (Table 1).

## 3. Wind atlas of Iran

It has been anticipated that Iran’s wind atlas will be ready in 2010. Preliminary studies led to the identification of some different geographical locations in the country that are suitable for generating electricity from the wind energy, the Manjil Tunnel (Gilan-Manjil), Takestan, Shahriar, Tehran, Semnan, Khorasan, Neishabur, Sabzevar, Badqais in Khorasan Province, Mashhad all the way down to Khaf, Torbat Heidarieh, as well as the provinces of Ardebil, East and West Azerbaijan, Kordestan, Hamedan, Kermanshah, Ilam, Isfahan, Kerman, Fars and the regions located in the south parts of Sistan and parts of the southern coasts are capable of producing 6500 MW of electricity generated from the wind energy. According to international and local renewable energy experts Iran possesses wind and other renewable energy resources which may be characterized as ‘‘world class’’, but the Iranian wind resource has not yet been mapped out in detail, and existing data is not easily available. During the project preparation the wind resources in the Manjil area were assessed based on existing data from a local meteorology station and found to be in line with Danish Class 1/ good European sites [1].

## 4. Climate

### 4.1. Iran

Iran has a complex climate, ranging from subtropical to sub polar. In winter, a high-pressure belt, centered in Siberia, slashes west and south to the interior of the Iranian Plateau, while low pressure systems develop over the warm waters of the Caspian, the Persian Gulf, and the Mediterranean. In summer, one of the lowest pressure centers in the world prevails in the south [1].

Low pressure patterns in Pakistan generate two regular wind patterns: the Shamal, which blows from February to October north-westerly through the Tigris-Euphrates Valley, and the 120-day summer wind, which sometimes reaches velocities of 70 miles/h in the Seestan region near the Pakistan frontier. Warm Arabian winds bring heavy moisture from the Persian Gulf. The gulf area, where the heat and humidity are unbearable, stands in sharp contrast to the Caspian coastal region, where moist air from the sea mingles with the dry air currants from the Alborz to create a soft nightly breeze. It is located within 25–40° latitude and being under great near continental pressure. The near continental region means that the sun shines perpendicularly in equational regions in the afternoons. The dry air also goes to the two poles (the South Pole and the North Pole). The arid air that blows toward the North Pole passes over the Iranian territory that is situated in the northern hemisphere [1]. Iran’s geographical situation is such that its low air pressures in comparison with high pressures in the north and northwestern regions produce strong air flows over it in general during the summer and winter months. During the winter months it is the difference in the air pressure between the atmospheres over Iran; center Asia as well as the Atlantic Ocean that causes cold winds from north and humid air flows from the Atlantic and Mediterranean from west. When these systems of air maldes collide with the humid air from the Mediterranean, cools off Iran

producing snow over the country. During the summer Iran is also affected by winds from the Atlantic Ocean on the northwest and by the winds from the Indian Ocean from the southeast; of the well known winds from the east are the 120 day winds of sistan and lavas wind: the other local winds in the country include the north winds on the Persian gulf and Khoch a bad winds in the Gorgan plain, deez wind between Mashhad and Nayshabour and sham winds in Khuzestan [7].

### 4.2. Yazd

Yazd is the driest major city in Iran, with an average annual rainfall of only 60 mm (2.4 in.), and also the hottest north of the Persian Gulf coast, with summer temperatures very frequently above 40 °C (104 °F) in blazing sunshine with no humidity. Even at night the temperatures in summer are rather uncomfortable. In the winter, the days remain mild and sunny, but in the morning the thin air and low cloudiness cause very cold temperatures that can sometimes fall well below 0 °C (32 °F) [12].

## 5. Prediction of the world wind power market from 2008 to 2010

The world-wide wind energy installed capacity will have doubled its existing amount (that is 134.8 GW) by the end of the coming decade. The world will experience the average of the annual growth rate of 18% between 2007 and 2010, while the growth rate was 28% between 2002 and 2007.

The annual installed capacity will grow by 55% from 11.5 GW in 2007 to 17.8 GW in 2010, so the average of the annual growth rate will be 9.1% in the world market of wind energy, Even if the amount can exceed the mentioned rate. However, it takes at least two years to receive the wind equipment and machinery (Tables 2 and 3).

According to the predictions, the wind energy production will be reduced in Europe compared to the past. Although European countries produced 55% of the total wind energy in 2007.

So there has been a decrease in the total installed capacity compared with the previous year. However, the wind power generation will go on. The reports show the annual growth rate will be 13.5 during 2006–2010 which accounts for 48% of the world-wide installed capacity.

Europe will have increased to 77.6 GW by the year 2010, 57% of the world-wide installed capacity [13].

A delay in the development of offshore wind energy market has made the expansion of large-scale onshore wind farm slow.

The development of onshore wind energy causes the process to progress more than ever [13].

The share of European markets will undergo some changes too.

At the turn of the 20th century, the most modern turbines were introduced to the markets all around the world, but the most active countries in this field are Germany, Spain, Denmark, India and the USA [9].

Although Germany and Spain occupy the top positions in generating wind energy in Europe, the strengthening of other European market may decrease their relative importance.

Spain should increase its annual capacity to 2000 MW. It will add 10,000 MW to its original capacity during 2006–2010, reaching the energy target of 20,000 MW for the year 2010.

**Table 3**
World wind energy installed in Megawatt for three years.

| | Japan | Austria | Greece | Australia | Iran | Mexico | Rest of | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | EU | America | Asia |
| 2005 | 1061 | 819 | 573 | 708 | 129 | 6 | 38 | 31 | 12 |
| 2006 | 1394 | 965 | 746 | 817 | 163 | 36 | 38 | 31 | 12 |
| 2007 | 1538 | 982 | 871 | 824 | – | 70 | – | – | – |

Although there will be decrease in the German wind energy market, it ranks second in the world with the extra capacity of 6600 MW during 2006–2010 and the highest wind power installed capacity (25,000 MW in 2010).

According to the predictions made, England, France and Portugal will be important players in the European market. They each add 4000 MW to their wind energy capacity during 2006–2010.

The North American market will experience the highest growth rate. According to the predictions made, the mean annual growth rate of 24.3% of the installed capacity in 2005 was 9.8 GW and would increase to 29.1 GW in 2010.

The US wind energy market occupies the top position with the highest average of 3000 MW during 2006–2010.

Even the tax exemption rendered to the producers may expire by the end of 2007; the evidence shows that it will be extend again. So, the growing number of state producers persuaded to generate the power wind may result in the stronger wind power market than before. The wind power capacity will exceed the predicted capacity of 15,000 MW and equate Germany by the year 2010 regretting the total installed capacity.

The studies indicate that Canada will experience an extra ordinary growth rate. It is anticipated that the total installed capacity will reach 5000 MW by the year 2010, that is, Canada will have the capacity of 4300 MW installed, through which, it will be the top five countries of wind generators. Asia owns a large share of the market with the predicted annual growth rate of 23.5% during 2006–2010.

The total installed capacity of Asia must increase from 7 GW in 2005 to 20.1 GW in 2010. India occupies the top position in Asia with the installed capacity of 6000 MW during 2006–2010 and ranks fourth world-wide. Pakistan is poorest of the poor nation as per capita consumption of energy is amongst the lowest in the world, being one-sixth of the world average and about half of the average of the developing countries but even then it has energy deficits of 40% [14–16] 74.4% population uses wood animal waste, 4% uses kerosene oil and 9% gas for cooking food [16]. At present, the share of renewable energy sources in Pakistan is very small. However, Pakistan's goal is to have 10% of national electricity generation come from alternative sources by 2010 [17–19]. A close look at the data will show that wind speeds are generally weak in the south, except for the coastal regions, and are strongest in the hilly regions of the north [20,21].

Some 3–5% of the Iranian population or about 3,250,000 people are still without the services of electric power in Iran. These people live in some 43,200 villages of power then 20 families. Taking into account villages in well-situated areas, 1300, 10 kW wind turbines will be needed [7].

Regarding the growth rate of wind power, China ranks second with the predicted capacity of 3800 MW. Japan ranks third with the installed capacity of 1500 MW and a lower growth rate.

**Table 2**
World wind energy installed in Megawatt for three years.

| | Germany | USA | Spain | India | China | Denmark | Italy | France | UK | Portugal | Canada |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | 18450 | 9149 | 10028 | 4430 | 1260 | 3136 | 1718 | 757 | 1332 | 1022 | 683 |
| 2006 | 20622 | 11603 | 11615 | 6270 | 2604 | 31470 | 2123 | 1567 | 1963 | 1459 | 1459 |
| 2007 | 22247 | 16818 | 15145 | 8000 | 6050 | 3129 | 2726 | 2454 | 2389 | 2150 | 1856 |

Korea and Taiwan rank fourth and fifth, respectively. It is estimated that the maximum potential of wind energy in Korea is 660 TWh/year. Due to the effort to exploit the wind energy, 71 MW of wind power plants was installed and operated [22,23].

There is no market for wind power in Latin America. It had only a little new capacity installed in 2005. It is anticipated that Brazil and Mexico will develop the wind power market in Latin America. Argentina and Chili will come to the market later. By the end of the coming decade, Latin America would not be playing a major role in the market in spite of its high potentials. Latin America's market is expected to grow more in the next decade.

Australia and New Zealand have taken the first steps to develop the wind energy, in 2005 Australia ranked 10th in the world the installed capacity of 370 MW. In spite of the instability caused by the political issues, the wind power market is expected to grow more during 2006–2010, ranking 10th in the world again. The country had no extra capacity installed in 2005. However, there are some projects under way, it will have the additional capacity of 800 MW installed by the year 2010 [13].

Africa will have the least wind power growth. Egypt and Morocco have taken steps to develop the wind power generation. The wind power will grow more rapidly than before in both countries.

It was anticipated that all countries in north Africa and Middle East, all together will add 1000 MW to their installed capacity in 2006. But the former Soviet Union is not expected to develop the wind power capacity, because of high reserves of oil and gas in that region [13].

A close look at the data will show that wind speeds are generally weak in the south, except for the coastal regions, and are strongest in the hilly regions of the north [20,21].

Sub-Saharan countries are facing severe and interrelated problems of energy, water and environment due to increased population pressure on land, biomass and other limited resources. This often leads to soil erosion, desertification, endangering of ecosystems and silting of rivers. This condition creates an enormous scientific and socio-economic challenge to the nations. The situation is worse in poor rural and urban communities where people live outside cash economy and are politically weak [24].

It has been recorded that a lot of efforts were applied to introduce Renewable Energy Technologies (RETs) between early 1970s and 1990 as a cure for Sub-Saharan Africa's deteriorating energy situation because they were perceived to be low-cost and an appropriate alternative to conventional energy technologies for use by the rural and urban poor of Africa [24,25].

Africa's population increased sharply from 364 million in 1970 to almost 800 million in 1999 accounting for about 13% of the world's total, and is projected to reach 1.3 billion by 2020 [26]. Sub-Saharan Africa has 43 countries with a population that accounts for about 10% of the world's total [27]. Africa's power sector has surplus energy resources but very low access to them by its population due to relatively low power infrastructure [28,29], a situation that impacts negatively on the prosperity and environmental diversity in the region. Millennium Development Goal is to halve extreme poverty and to reverse loss of environmental resources by 2015 [30].

Malawi is a small but densely populated land-locked country in the southern Sub-Saharan Africa, lying between latitudes 09°25′S and 17°08′S, and longitudes 32°40′E and 35°55′E. It has a total area of 11.8 million hectares consisting of 9.4 million hectares of land, and the rest covered by water bodies, the largest of which is Lake Malawi. Malawi shares boundaries with Tanzania to the north, Mozambique to the east, south and west, and Zambia to the west. Projections from the 1998 national population census show that Malawi's population is 11 million. Of the population 34.4% are without access to safe water, 30% are without access to improved sanitation [31–33] and 94% are without access to electricity [34,35]. The later is an improvement from 97% in 1997 [24,25].

**Table 4**
The annual figures for electricity production from renewable energy sources worldwide [40].

| Order number | Source of energy | Power (MW) | Energy (billion of KWh |
|---|---|---|---|
| 1 | Water | 669000 | 2690 |
| 2 | Geothermal | 7900 | 49 |
| 3 | Wind | 13500 | 23 |
| 4 | Solar | 325 | 0.9 |
| 5 | Photovoltaic | 700 | 0.7 |
| 6 | Total | 700000 | 2800 |

The target group is initially the rural population, which constitutes 85% of the Malawi population [31,32], where a 5 kW generator is estimated to service an average Malawian village and by replicating the service a large proportion can have access to power [24].

Upon successful dissemination, the technology could be adopted for other Sub-Sahara countries with similar wind regimes to those in Malawi. Like Zambia, Malawi's average annual wind speeds are low [24,25,48].

It was established that the wind speeds in Malawi range from 3.72 m/s to 5.63 m/s at 2 m and 10 m heights, respectively [49], suitable for slow speed fixed pitch windmills, a situation very similar to the wind power resource in Pakistan [36]. There are some sites with mean wind speeds of up to 10 m/s. Speed and power increases of 10–20% and 30–70%, respectively, usually occur over ridges. It is windy from July to November and in pursuance to generally acceptable WET siting practice, they were compared with seasonal demands of water and energy [37–39]. The windy season was found to coincide with high water and energy demands which are a great motivator to the technological advancement [24].

Renewable energy sources include water, wind, geothermal, solar, etc. Table 4 shows the extent of utilization of wind energy for producing electricity in comparison with the use of other renewable energy sources [40]. It can be seen that of the 2800 billion kWh of energy utilized more come from hydroelectric sources. Wind energy with a total power of 13,500 MW produces about 23 billion kWh of electricity ranks third among the renewable energy sources [7,41].

## 6. Wind energy activities in Iran

There have been historically wind mills in Iran since the windmills date from around 2000 B.C. in Iran due to the wind development zones and it will be an ideal location for the establishment of the wind turbines.

The wind power generators can be a suitable alternative to the steam and gas plants.

The wind data collection indicates existence of 26 ideal sites with the total potential wind power of 6500 MW, while the nameplate capacity of the power plants is 34,000 MW. The wind generators are practical where the average wind speed is 5–25 m/s [10,43]. The above average wind speed should be considered at 40 m height above the ground.

Iran's wind department and the Renewable Organization of Iran (Suna) are in charge of the planning, managing, controlling the programs and using the wind potentials of the country.

The actions taken by them are as follows [10]:

1. The design management, production, and installation of the 10 kW wind turbine in Tabriz.
2. The design management, production, and installation of the 600 kW wind turbine in Manjil.
3. The management and exploitation of 2 units of 130 kW wind turbines in Dizabad of Khorasan province.

4. The wind potential measurement and preparation of the wind atlas for Iran.
5. The installation of 10 units of 10 m and 40 m wind potential measurement stations in Gilan province.
6. The installation of 7 units of 10 m and 40 m wind potential measurement stations in provinces of Eastern Azerbaijan, Western Azerbaijan, and Ardebil.

## 7. Survey on wind energy in Iran

With the total area of 1,648,195 km$^2$, Iran is located in the northern hemisphere in the east of Asia (one of the countries in the Middle East). The east meridian of 44.5 draws along the western most part of Iran and the east meridian of 63.8 draws along the eastern most part. Its land borders are with former Soviet States of Azerbaijan, Armenia and Turkmenistan, 2013 km to the north, Pakistan (978 km) and Afghanistan (945 km) to the east, Turkey (486 km) and Iraq (1609 km) to the west. Its water borders are with the Caspian Sea from the Astara river to the Gulf of Hosseinqoli (657 km) to the north, the Gulf of Oman in southwest from the Goatr to the Bandar-Abbas (784 km) and the Persian Golf from Bandar-Abbas to the mouth of Arvand Roud (125 km) to the south. Iran is 8731 km in circumference. Iran consists of the Iranian plateau (90% of its total area) with the exception of the coasts of the Caspian Sea and Khuzestan. It is considered a mountain country in which more than half of the area is covered with the mountain ranges, 1.4% by the desert and less than 1.4% by the arable land [10,42].

Iran has a variable climate and a comparison among different areas shows the variety of climates. The rugged mountain ranges, located in the north, are too high for rain clouds to reach these regions, so the northern edge (the Caspian coastal plain) remains humid. In the southern part of the Caspian coast, the weather in mild and the annual precipitation, especially in Gilan province (western part of Caspian Sea) is more than the other regions. The average summer temperature is about 18°C, but the western part experiences the Mediterranean weather. The southern part which is influenced by the salt desert, the weather is mild and in the valleys it is very hot in summer [10,46].

In winter, it is mild in the valleys and it is subzero freezing. In the south, summer heat is accompanied by high humidity. The temperature sometimes reaches 54°C. Summer is usually hot and winter is mild. There is not much difference between the day and night temperatures. The Zagro Mountain, in the west, and Alborz Mountain ranges in the north, have left the interior part of the Iranian plateau arid. The northern and western foothills are influenced by the mild weather of the neighboring areas [10,46].

As we go from the west to the east and north to the south, the effect of humid winds declines and the heat goes up. In the central lowlands and in the east and south east of Iran the temperature is freezing in winter and it is very hot in summer. There is a sharp contrast between day and night temperatures [10,46].

Iran is surrounded by the rugged mountainous rims. It is located between the west and the east, the south (hot) and the north (mild), being affected by the main air currents coming from Asia, Europe, Africa, the Pacific and Atlantic Oceans.

The determining factors are latitudes, the north and south poles, the elevation from the sea level, the presence of the mountains or plains, the sea, the lake, the pressure of the air, wind and precipitation.

Iran is located in the southwest of Asia, its central borders continue into the central Asia, the high mountain ranges, rimming it provides the country with a variety of climates [10,42].

The winds blowing from the Atlantic Ocean and the northeast, the central Asia, occur in winter and the winds coming from the Iceland, Scandinavia and the Pacific Ocean occur in summer and all the atmospheric currents are influenced by them.

Iran has been affected by following atmospheric currents [10,43]:

1. The main pressure center in the central Asia in winter.
2. The main pressure center in the Pacific Ocean in summer.
3. The west current blowing from the Atlantic Ocean and the Mediterranean especially in winter.
4. The northwest current in summer.

## 8. Future of wind energy in Iran

Energy production market is a competitive one and the total amount of economically extractable power available from all sources.

Some countries have increased their wind generation capacity, setting an example for the other countries which have begun to take steps. Many of the economic developmental sources are located in Asia. The developing economy in Asia, including Iran, is capable of implementing most of the renewable sources of energies. Asian countries have been aware of their desperate need to generate electricity, using the non-fuel resources. The lake of power-supply in some rural areas enhances the development of the wind power generation [10,43,45].

Regarding the prospect of the wind energy in Iran, it can be said that the use of the wind energy will lead to saving in fuel, bringing about the preservation of the oil products. It will also help to preserve the environment and leads us to the dynamic social and economical development.

The wind power generation will bring growth, development and job opportunities, finally when the wind energy technology is well established, the economy will improve.

## 9. Wind energy in Yazd

### *9.1. Wind function*

Winds in Yazd province undergo two kinds of fluctuations.

#### *9.1.1. The seasonal fluctuations*

The winds pick up in spring and drops in winter, they reach their peak in summer and this makes it necessary to predict the appropriate ways to provide the farmers with the electricity needed.

#### *9.1.2. The daily fluctuation*

Besides the seasonal changes, the winds in Yazd can be variable at several different timescales: from hour to hour, daily at midnight, the wind begins to drop; it remains low until early morning.

At middy, the wind reaches its peak. Since the deserts lack trees and plants, they have a dampening effect on wind speed. The winds sweep over the desert with the speed of about 90 km/h. The speed of about 120 km/h was also recorded.

### *9.2. Wind rose diagram*

The wind has a variable speed; besides, its direction varies all the time. Due to the electronic and mechanical control system, the wind turbines are always stationed in the direction of the winds and they make the most of the wind energy, so the direction of the wind does not play an important role in the selection of the location and the design of the wind turbine [44].

However, the direction of the wind is taken into consideration when the turbines are installed in the wind farm.

Some information has been obtained from 1994 to 2005 for cities of Yazd, Bafgh, Tabas, Rabat and Marvast. It should be noted that the software of 'windrose' has been used for this purpose [10].

Based upon the following wind rose diagram (Fig. 1), the wind blows mainly from the west and northwest in city of Yazd. For city

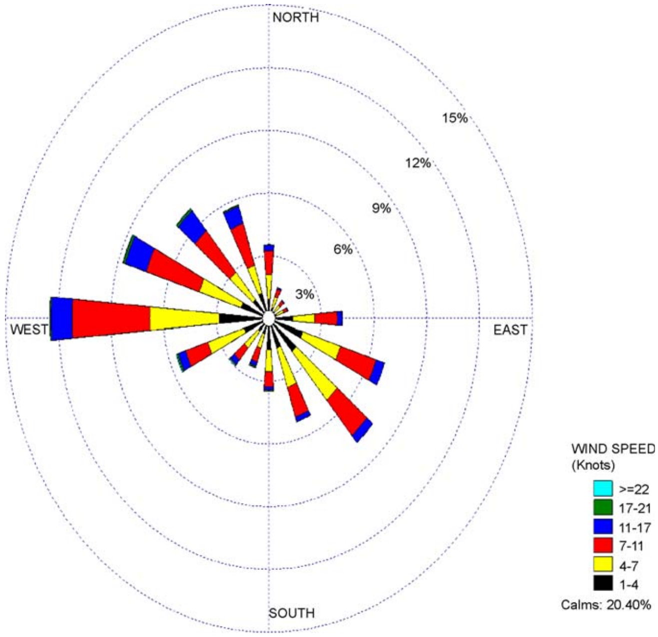


**Fig. 1.** Wind rose diagram for city of Yazd from 1994 to 2005 [44].

of Bafgh, wind blows mainly (Fig. 2) in directions of northwest and southeast. Fig. 3 shows that wind direction for city of Tabas is northeast. Fig. 4 shows the directions of south and north for city of Marvast, and finally Fig. 5 is about city of Rabat with its majority of winds in north direction [10].

## 10. Location planning

The theory of the location planning was rendered in Germany in the 19th century together with the agricultural location planning; it was developed with the industrial location planning offered by Alfered Webrer.

Since the 1950, other economists have taken to develop the regional and analytical techniques by the scientific methods of analysis the space as well as the location and economic use of lands.

The 1960, can be regarded as turning point of the views of the improvement of land, because the environmental theories regarding the establishment of environmental ecosystem were added to the views about the improvement of land [10]. The location planning was always performed in industrial projects based on the economic and technical factors. These methods and techniques did not involve the interactions [45].

In order to solve the problem, it is necessary to design an analytical framework through which the different environmental elements are explained and classified, so, the technical and economic elements should be applied.

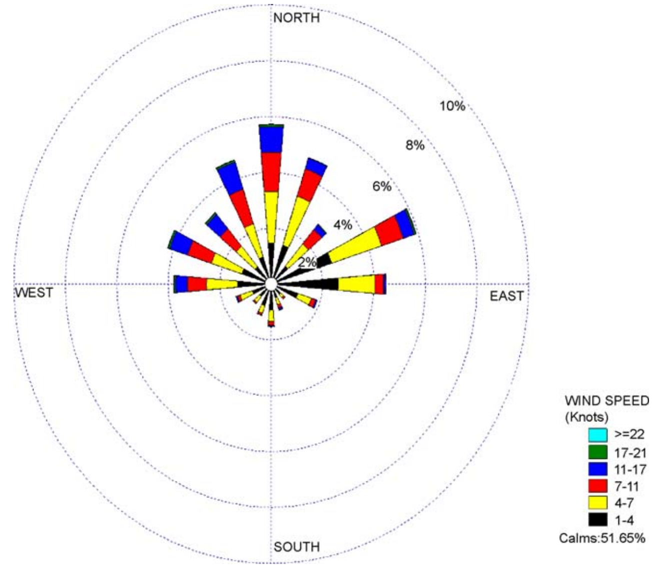


**Fig. 3.** Wind rose diagram for city of Tabas from 1994 to 2005 [44].

### 10.1. Location of the wind towers in Yazd province

All the information about the wind speed of 11 different regions for up to 13 years has been obtained from the meteorological organization of Yazd. The wind speed at the height of 10 m was provided while the ideal height for the large turbine sitting is 40 m.

By using the formulas, the wind speed at 40 m elevation has been obtained and the ideal turbine sitting has been selected by analysis of the wind data.

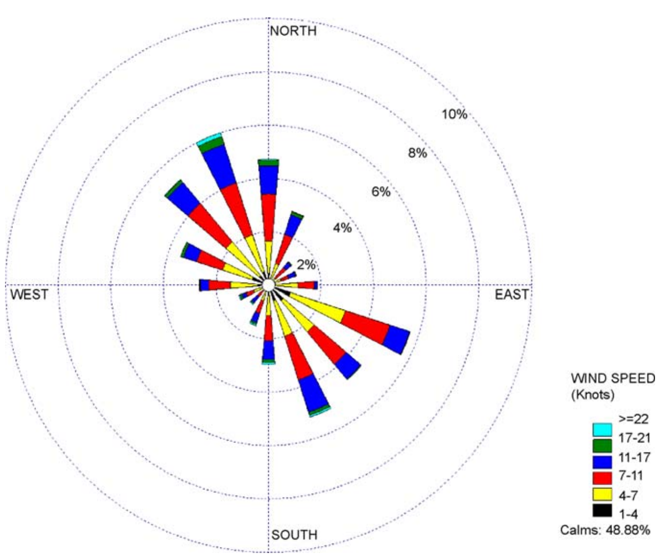


**Fig. 2.** Wind rose diagram for city of Bafgh from 1994 to 2005 [44].

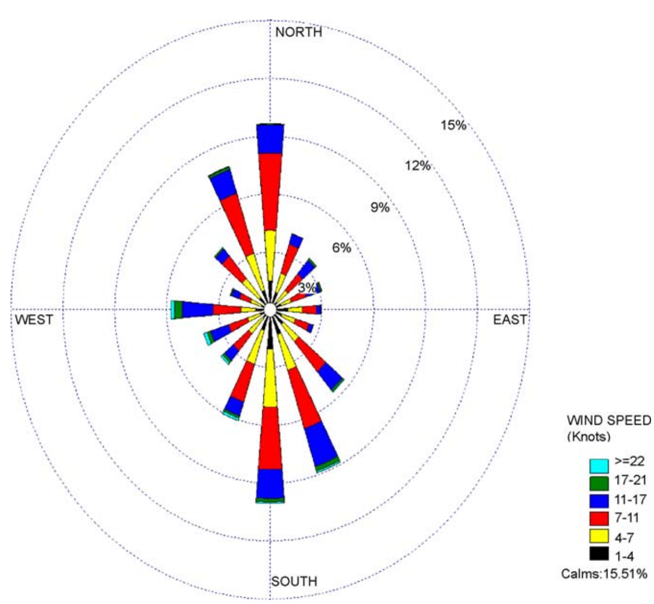


**Fig. 4.** Wind rose diagram for city of Marvast from 1994 to 2005 [44].

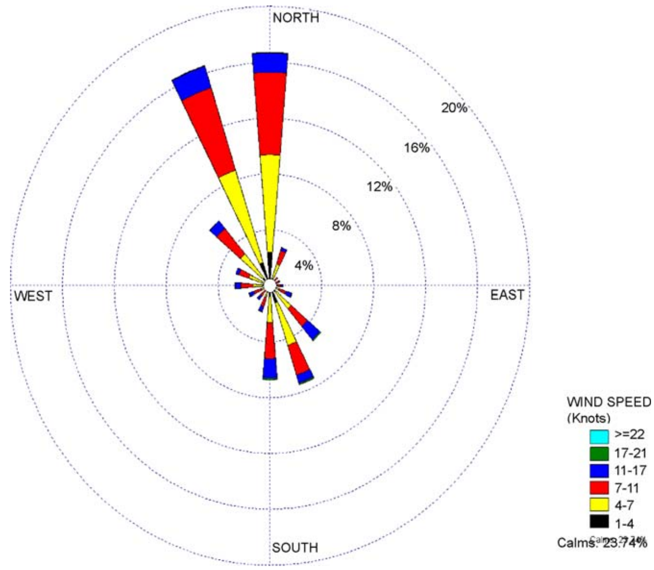


**Fig. 5.** Wind rose diagram for city of Rabat from 1994 to 2005 [44].

### 10.2. Extrapolation of wind speed

The wind speed data used in this research were measured from the stations at a standard height of 10 m. The speed at any height can be calculated by formula.

The meteorological data can be appropriate when the context of the earth is similar to the context of the meteorological upwind obstacles such as trees or buildings.

The wind blows more slowly at lower height, because of the increased influence of drag of the surface and lower are viscosity. While the wind speed rises proportionally to the seventh root of attitude, in fact at a definite attitude, the friction disappears and the speed of the air molecules can be the function of the pressure gradient force and it is usually called the gradient elevation (height). So, we can calculate the wind speed at any height by knowing the wind speed at a given height.

$$\frac{V_z}{V_z} = \left(\frac{z}{z_{10}}\right)^{\alpha}$$

$V_z$ is the wind speed at the required or extrapolated height $z$.

$V_z$ is the actual wind speed at the height of 10 m.

The exponent $\alpha$ is also roughness coefficient which depends on characteristic of the surface of the land and its value can be selected from Table 5.

In this paper, the average speeds at 20 m and 40 m have been calculated using the value for $\alpha$ at the specified heights [46].

This formula can be used to adapt the average wind speed of the watch height to the desired one at the similar meteorological stations.

The value of $\alpha$ could also be obtained from the following formula too:

$$\alpha = \frac{[0.37 - 0.088 \ln V_{10}]}{[1 - 0.088 \ln(z_{10}/10)]}$$

The Roughness value for different cities of Yazd province could be obtained from Table 5 based upon the characteristic of the land as was shown in Table 6.

In order to analyze the tables and charts, and their suitability for the turbine installation, the following table has been used for potential value of wind speed. The best wind speed for installing the wind turbine is 6.7 m/s and more, but it should be mentioned that it is not safe to install wind turbines in areas with wind speed of more than 11 m/s, because of the possibility of damage to the system.

**Table 5**
Roughness value ($\alpha$) and gradient elevation for different lands.

| Type | Characteristic of land | Gradient elevation (m) | $\alpha$ |
|---|---|---|---|
| I | Sea and icy land | 250 | 0.11 |
| II | Villages with scathered trees | 300 | 0.15 |
| III | Small cities | 400 | 0.25 |
| IV | Tall buildings and big cities | 500 | 0.36 |

**Table 6**
Value of $\alpha$ for different cities in Yazd province.

| City | Roughness value ($\alpha$) |
|---|---|
| Yazd | 0.29 |
| Bafgh | 0.22 |
| Tabas | 0.22 |
| Marvast | 0.20 |
| Rabat | 0.15 |
| Maybod | 0.22 |
| Mehriz | 0.22 |
| Aghda | 0.22 |
| Herat | 0.20 |
| Gariz | 0.26 |
| Abarkouh | 0.22 |

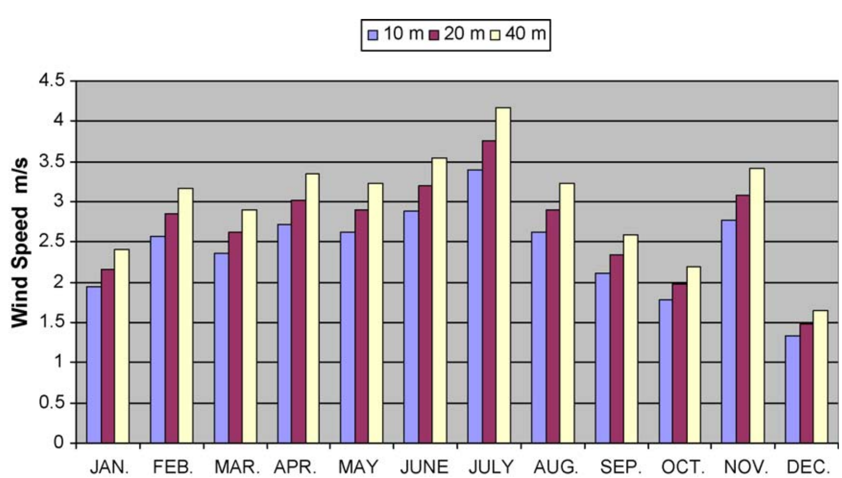


**Fig. 6.** Wind speed for city of Rabat in 1992.

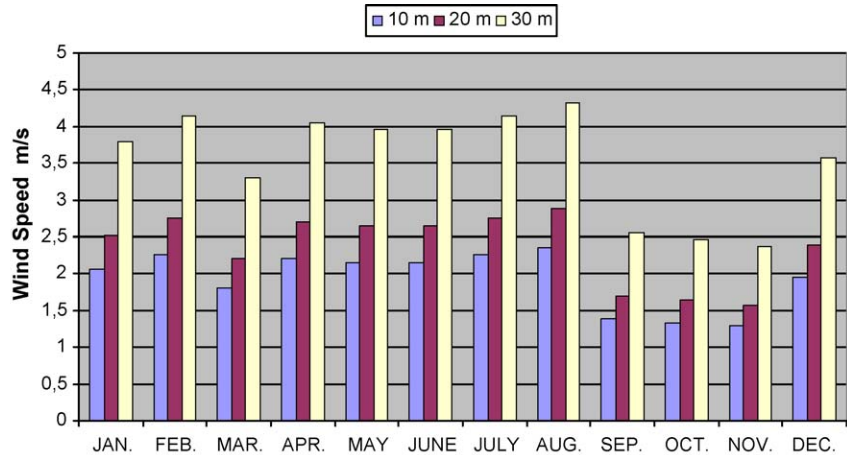


**Fig. 7.** Wind speed for city of Yazd in 1992.

**Table 7**
Potential value for average annual wind speed at height of 10 m [47].

| Annual mean wind speed at 10 m height | Indicated value of wind resource |
|---|---|
| Less than 4.5 m/s | Poor |
| 4.5–5.4 m/s | Marginal |
| 5.4–6.7 m/s | Good to very good |
| More than 6.7 m/s | Exceptional |

## 11. Wind speed information for cities in different years

The wind speeds in the different areas at the heights of 10 m, 20 m and 40 m have been shown. The peak wind speed, average direction of the wind speed has been given too. The distribution of the wind speed is rendered in each month.

### 11.1. Wind speed information for three cities in 1992

The figures ranging from 1 to 3 show the wind speed in three different cities in province of Yazd, in different months for 1992. Based upon the information from Yazd meteorology organization, only data from cities of Yazd, Tabas, and Rabat were available for analyzing. City of Rabat (Fig. 6) has the highest mean wind speed of 2.43 m/s at 10 m height, but city of Yazd (Fig. 7) with 3.55 m/s at 40 m height have the highest wind speed in 1992; it is regarded very low for the turbine sitting. With these low mean wind speeds at the heights of 10 m, 20 m, and 40 m, none of the mentioned cities are good locations for installing the wind turbines, because their annual wind speeds are less than 4.5 m/s (Table 7) at 10 m above the ground.

The city of Yazd (Fig. 7) has the highest wind speed of 2.36 m/s in August at 10 m height, and 4.33 m/s at 40 m height while the lowest wind speed of 1.29 m/s at 10 m occurs in November. City of Yazd has the mean wind speed of 3.55 m/s at 40 m elevation, which is not a good place for installation of wind turbines.

With the mean wind speed of 2.32 m/s at 10 m height, city of Tabas (Table 8) has the highest wind speed in August and the lowest wind speed in November with speed of 1.03 m/s at 10 m elevation, which is equal to 1.10 m/s at 40 m (Fig. 8).

### 11.2. Wind speed information for four cities in 1993

Figs. 9–12 show the wind speed for cities of Yazd, Bafgh, Tabas and Rabat in different months for the year 1993. Of the four stations from which the information is obtained, Tabas has the highest potential (Table 9) with the mean speed of 2.41 m/s at 10 m, but Yazd with 3.69 m/s at 40 m/s has the highest speed at 40 m/s. It is obvious that none of these cities are capable of harnessing wind energy to be useful for installation of wind turbines.

With the mean wind speed of 2.01 m/s at the height of 10 m and 3.69 m/s at the height of 40 m, the city of Yazd (Fig. 9) has the highest wind speed in February, and July with the speed of 2.61 m/s and the lowest wind speed in October with the speed of 1.29 m/s at 10 m elevation.

City of Bafgh (Fig. 10) had the mean wind speed of 1.68 m/s at the height of 10 m, and 2.28 m/s at 40 m/s. Its highest wind speed

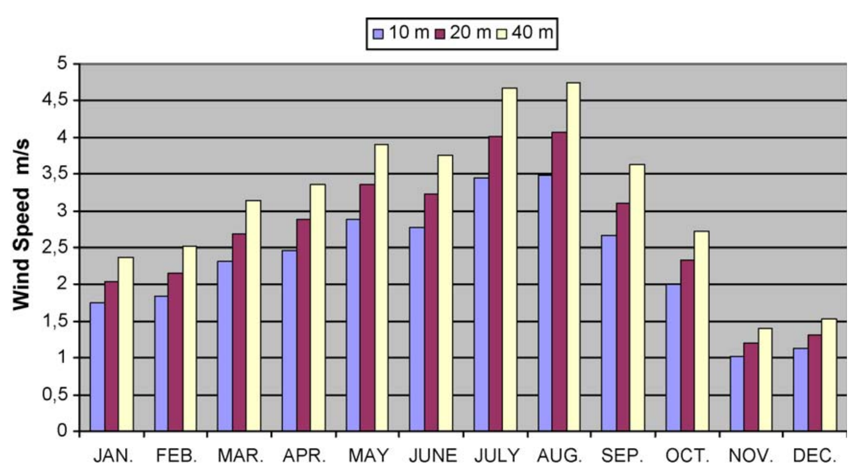


**Fig. 8.** Wind speed for city of Tabas in 1992.

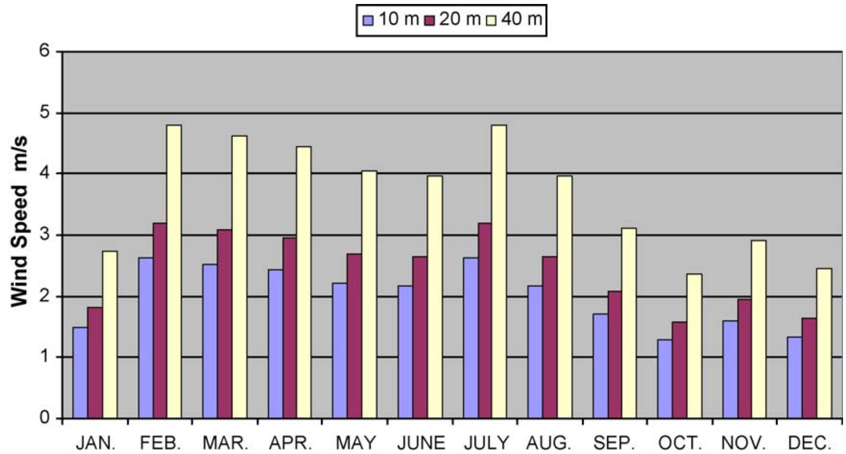


**Fig. 9.** Wind speed for city of Yazd in 1993.

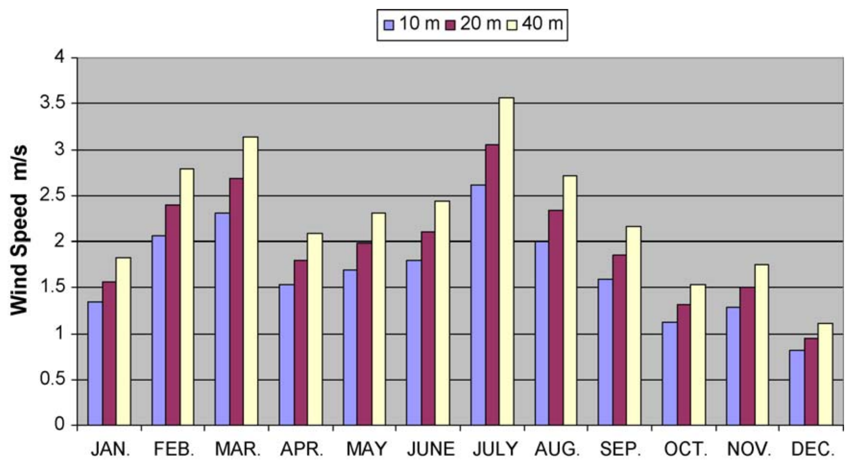


**Fig. 10.** Wind speed for city of Bafgh in 1993.

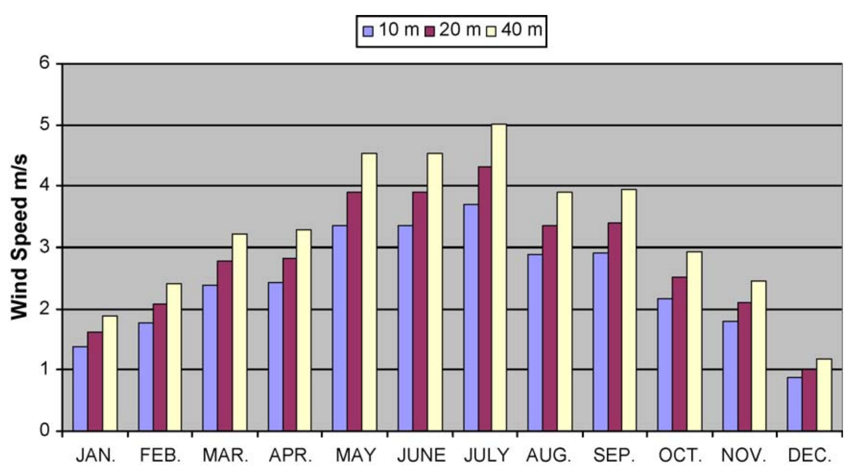


**Fig. 11.** Wind speed for city of Tabas in 1993.

**Table 8**
Annual wind speed at different elevations for 1992.

| City | $V_{10}$ | $V_{20}$ | $V_{40}$ | $V_{max}$ | Direction |
|---|---|---|---|---|---|
| Yazd | 1.94 | 2.37 | 3.55 | 12.81 | 245.00 |
| Tabas | 2.34 | 2.70 | 3.14 | 11.39 | 248.33 |
| Rabat | 2.43 | 2.59 | 2.98 | 9.21 | 230.00 |

**Table 9**
Annual wind speed at different elevations for 1993.

| City | $V_{10}$ | $V_{20}$ | $V_{40}$ | $V_{max}$ | Direction |
|---|---|---|---|---|---|
| Yazd | 2.01 | 2.46 | 3.69 | 12.42 | 256.67 |
| Bafgh | 1.68 | 1.96 | 2.28 | 9.42 | 268.33 |
| Tabas | 2.41 | 2.81 | 3.28 | 12.04 | 260.83 |
| Rabat | 2.27 | 2.52 | 2.79 | 10.45 | 248.33 |

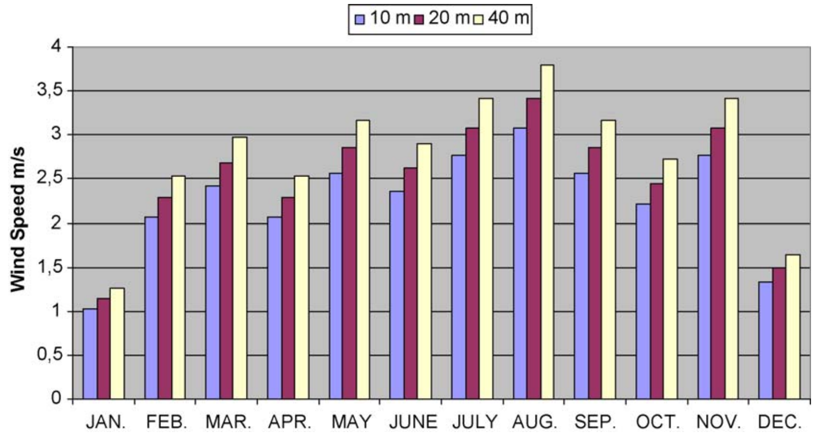


**Fig. 12.** Wind speed for city of Rabat in 1993.

was in July and lowest in December. It is not a good place for installing any kind of wind turbine (Table 9).

With the mean wind speed of 2.41 m/s at the height of 10 m, and 3.28 m/s at 40 m, city of Tabas (Fig. 11) had the highest wind speed in July. The lowest wind speed was in month of December. This city is not also a good choice for installing any kind of wind turbine.

City of Rabat (Fig. 12) had the mean wind speed of 2.27 m/s at the height of 10 m, the highest wind speed of 3.08 m/s in August, and the lowest wind speed of 1.03 m/s in December. It is not also a good site for installing any kind of wind turbine too (Tables 8 and 9).

### *11.3. Wind speed information for four cities in 1994*

Based upon the information obtained from four stations in cities of Yazd, Rabat, Tabas, and Bafgh in 1994, Rabat had the highest potential of harnessing wind at 10 m height with 2.40 m/s speed.

Average wind speed for City of Yazd at 10 m height was 1.92 m/s at 10 m, also calculated average wind speed at 40 m elevation was 3.52 m/s. Maximum mean wind speed of 2.72 m/s was for month of July, but the lowest mean speed of 1.08 m/s was for November.

For this year, the city of Bafgh with mean wind speed of 1.63 m/s at 10 m height, and 2.22 m/s at 40 m elevation had the lowest potential in case of wind turbine installation in province of Yazd. In September, Bafgh had the best wind speed of 2.16 m/s, but the lowest belonged to August with 1.19 m/s.

City of Tabas had the average wind speed of 1.83 m/s at 10 m elevation, and 2.49 m/s at 40 m height. Also maximum mean wind speed of 2.52 m/s was for month of July, but the lowest mean speed of 0.82 m/s was for month of November.

City of Rabat had the average wind speed of 2.4 m/s at 10 m elevation, and 2.95 m/s at 40 m height. Also maximum mean wind speed of 2.82 m/s was for month of August, but the lowest mean speed of 1.8 m/s was for January.

Based upon information from Table 10, none of these four locations are good for installation of wind turbine. But once a year wind speeds of more than 9 m/s blow in these cities, which is not sufficient.

**Table 10**
Annual wind speed at different elevations for 1994.

| City | $V_{10}$ | $V_{20}$ | $V_{40}$ | $V_{max}$ | Direction |
|---|---|---|---|---|---|
| Yazd | 1.92 | 2.35 | 3.52 | 12.76 | 236.67 |
| Bafgh | 1.63 | 1.90 | 2.22 | 9.64 | 265.00 |
| Tabas | 1.83 | 2.14 | 2.49 | 10.28 | 291.67 |
| Rabat | 2.40 | 2.67 | 2.95 | 9.98 | 199.67 |

### *11.4. Wind speed information for four cities in 1995*

Based upon the information obtained from four stations in cities of Yazd, Rabat, Tabas, and Bafgh in 1995, Rabat had the highest potential of harnessing wind.

Average wind speed for City of Yazd at 10 m height was 1.48 m/s, also calculated average wind speed (Table 11) at 40 m elevation was 2.71 m/s. Maximum mean wind speed of 1.90 m/s was for month of October, but the lowest mean speed of 0.87 m/s was for December.

For this year, the city of Bafgh with mean wind speed of 1.62 m/s at 10 m height, and 2.2 m/s at 40 m elevation had low potential in case of wind turbine installation in province of Yazd. In April, August and September, Bafgh had the best wind speed of 2.23 m/s, but the lowest belonged to December with 0.514 m/s.

City of Tabas had the average wind speed (Table 11) of 1.45 m/s at 10 m elevation, and 1.96 m/s at 40 m height. Also maximum mean wind speed of 2.47 m/s was for months of June, but the lowest mean speed of 0.26 m/s was for December. It had lowest potential among other four cities for capturing wind.

City of Rabat had the average wind speed of 2.35 m/s at 10 m elevation, and 2.89 m/s at 40 m height (Table 11). Also maximum mean wind speed of 3.24 m/s was for month of July, but the lowest mean speed of 1.18 m/s was for December.

### *11.5. Wind speed information for four cities in 1996*

Based upon the information obtained from four stations in cities of Yazd, Rabat, Tabas, and Bafgh in 1996; Rabat had the highest potential of harnessing wind at 10 m height, but Yazd had the highest potential at 40 m with speed of 4.47 m/s.

**Table 11**
Annual wind speed at different elevations for 1995.

| City | $V_{10}$ | $V_{20}$ | $V_{40}$ | $V_{max}$ | Direction |
|---|---|---|---|---|---|
| Yazd | 1.48 | 1.80 | 2.71 | 11.05 | 242.50 |
| Bafgh | 1.62 | 1.92 | 2.20 | 8.65 | 256.67 |
| Tabas | 1.45 | 1.68 | 1.96 | 11.91 | 216.67 |
| Rabat | 2.35 | 2.61 | 2.89 | 10.17 | 212.50 |

**Table 12**
Annual wind speed at different elevations for 1996.

| City | $V_{10}$ | $V_{20}$ | $V_{40}$ | $V_{max}$ | Direction |
|---|---|---|---|---|---|
| Yazd | 2.44 | 2.98 | 4.47 | 11.01 | 220.00 |
| Bafgh | 2.26 | 2.63 | 3.07 | 10.15 | 265.83 |
| Tabas | 1.51 | 1.75 | 2.04 | 10.19 | 265.83 |
| Rabat | 2.66 | 2.96 | 3.27 | 10.32 | 216.67 |

Average wind speed for City of Yazd at 10 m height was 2.44 m/s, also calculated average wind speed (Table 12) at 40 m elevation was 4.47 m/s. Maximum mean wind speed of 2.83 m/s was for month of December, but the lowest mean speed of 0.98 m/s was for January.

For this year, the city of Bafgh with mean wind speed of 2.26 m/s at 10 m height, and 3.07 m/s at 40 m elevation had low potential in case of capturing wind in province of Yazd. In July, Bafgh had the best wind speed of 3.49 m/s, but the lowest belonged to January with 1.03 m/s at 10 m elevation.

City of Tabas had the average wind speed of 1.51 m/s at 10 m elevation (Table 12), and 2.04 m/s at 40 m height. Also maximum mean wind speed of 3.19 m/s was for months of July, but the lowest mean speed of 0.51 m/s was for December at 10 m elevation.

City of Rabat had the average wind speed (Table 12) of 2.66 m/s at 10 m elevation, and calculated wind speed of 3.27 m/s at 40 m height. Also maximum mean wind speed of 4.01 m/s was for month of July, but the lowest mean speed of 1.64 m/s was for November at 10 m elevation.

### 11.6. Wind speed information for five cities in 1997

Based upon the information obtained from five stations in cities of Yazd, Bafgh, Tabas, Marvast, and Rabat in 1996, Marvast had the highest potential of harnessing wind.

Average wind speed for City of Yazd at 10 m height was 3.18 m/s, also calculated average wind speed at 40 m elevation was 5.83 m/s. Maximum mean wind speed of 3.80 m/s was for month of June, but the lowest mean speed of 2.57 m/s was for November at 10 m elevation.

For this year, the city of Bafgh with mean wind speed of 1.66 m/s at 10 m height, and 2.25 m/s at 40 m elevation had also low potential in case of capturing wind again in province of Yazd. In March, Bafgh had the best wind speed of 2.72 m/s on March, but the lowest belonged to December with 0.87 m/s at 10 m elevation.

City of Tabas had the average wind speed of 1.3 m/s at 10 m elevation, and 1.77 m/s at 40 m height. Also maximum mean wind speed of 2.47 m/s was for months of June, but the lowest mean speed of 0.51 m/s was for December at 10 m elevation.

City of Marvast had the average wind speed of 3.98 m/s at 10 m elevation, and 5.28 m/s at 40 m height. Also maximum mean wind speed of 5.46 m/s was for months of March, but the lowest mean speed of 2.98 m/s was for September at 10 m elevation.

City of Rabat had the average wind speed of 2.91 m/s at 10 m elevation, and calculated wind speed of 3.58 m/s at 40 m height. Also maximum mean wind speed of 3.91 m/s was for month of July, but the lowest mean speed of 1.7 m/s was for November at 10 m above the ground (Table 13).

### 11.7. Wind speed information for five cities in 1998

Of the five stations from which the data have been received; city of Marvast had the highest potential for wind energy with the mean speed of 3.99 m/s and 5.26 m/s at the heights of 10 m and 40 m, respectively.

With the mean wind speed of 3.16 m/s and 5.80 m/s at the height of 10 m and 40 m, respectively, city of Yazd had the highest wind speed of 3.96 m/s in July, also the lowest wind speed of 2.26 m/s in November at 10 m height above the ground.

With the mean wind speed of 1.58 m/s and 2.14 m/s at the height of 10 m and 40 m, respectively, city of Bafgh had the highest wind speed of 2.31 m/s in August, also the lowest wind speed of 1.03 m/s in December at 10 m height.

City of Tabas had the mean wind speed of 1.25 m/s at the height of 10 m, and 1.69 m/s at the height of 40 m with the highest wind speed of 2.36 m/s in June and July; also the lowest wind speed of 0.21 m/s in December at 10 m elevation above the ground.

City of Marvast had the proper wind potential with the mean speed of 3.99 m/s at the height of 10 m, and 5.26 m/s at the height of 40 m. Highest wind speed of 5.14 m/s occurs in January, and the lowest wind speed of 2.42 m/s in November at 10 m height. City of Rabat had the mean wind speed of 2.81 m/s at height of 10 m, and 3.46 m/s at 40 m elevation. Highest wind speed of 3.6 m/s occurs in August, and the lowest wind speed of 2.21 m/s in January at 10 m elevation. Of the five stations studied, Marvast is the most ideal site for installation of wind turbines (Table 14).

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**Table 14**
Annual wind speed at different elevations for 1998.

| City | $V_{10}$ | $V_{20}$ | $V_{40}$ | $V_{max}$ | Direction |
|---|---|---|---|---|---|
| Yazd | 3.16 | 3.89 | 5.80 | 13.41 | 247.50 |
| Bafgh | 1.58 | 1.84 | 2.14 | 7.54 | 243.33 |
| Tabas | 1.25 | 1.45 | 1.69 | 9.81 | 322.50 |
| Marvast | 3.99 | 4.59 | 5.26 | 11.52 | 271.50 |
| Rabat | 2.81 | 3.12 | 3.46 | 9.55 | 206.67 |

### 11.8. Wind speed information for five cities in 1999

Of the five stations from which the data have been received; city of Yazd had the highest potential for wind energy with the mean speed of 3.03 m/s and 5.56 m/s at the heights of 10 m and 40 m, respectively. City of Yazd had the highest wind speed of 3.58 m/s in July, also the lowest wind speed of 2.47 m/s in December at 10 m elevation.

With the mean wind speed of 1.47 m/s and 2.00 m/s at the height of 10 m and 40 m, respectively, city of Bafgh had the highest wind speed of 2.31 m/s in July, also the lowest wind speed of 0.97 m/s in December at 10 m, elevation.

City of Tabas had the mean wind speed of 1.30 m/s at the height of 10 m, and 1.77 m/s at the height of 40 m with the highest wind speed of 2.62 m/s in August and the lowest wind speed of 0.46 m/s in February at 10 m elevation.

City of Marvast had the mean speed of 3.02 m/s at the height of 10 m, and 3.98 m/s at the height of 40 m. Highest wind speed of 3.55 m/s occurs in April, and the lowest wind speed of 2.36 m/s in October at 10 m elevation.

City of Rabat had the mean wind speed of 2.89 m/s at height of 10 m, and 3.56 m/s at 40 m elevation. Highest wind speed of 3.65 m/s occurs in July, and the lowest wind speed of 2.11 m/s in January at 10 m elevation.

Of the five stations studied, city of Yazd is the most ideal location for installation of wind turbines. But based upon the

**Table 13**
Annual wind speed at different elevations for 1997.

| City | $V_{10}$ | $V_{20}$ | $V_{40}$ | $V_{max}$ | Direction |
|---|---|---|---|---|---|
| Yazd | 3.18 | 3.89 | 5.83 | 14.56 | 273.33 |
| Bafgh | 1.66 | 1.93 | 2.25 | 8.31 | 231.67 |
| Tabas | 1.30 | 1.52 | 1.77 | 11.69 | 255.00 |
| Marvast | 3.98 | 4.58 | 5.26 | 12.68 | 245.83 |
| Rabat | 2.91 | 3.23 | 3.58 | 10.32 | 191.67 |

**Table 15**
Annual wind speed at different elevations for 1999.

| City | $V_{10}$ | $V_{20}$ | $V_{40}$ | $V_{max}$ | Direction |
|---|---|---|---|---|---|
| Yazd | 3.03 | 3.71 | 5.56 | 12.51 | 288.33 |
| Bafgh | 1.47 | 1.72 | 2.00 | 7.58 | 225.83 |
| Tabas | 1.30 | 1.52 | 1.77 | 10.11 | 251.67 |
| Marvast | 3.02 | 3.47 | 3.98 | 11.05 | 220.82 |
| Rabat | 2.89 | 3.21 | 3.56 | 9.25 | 192.50 |

values of Table 7, its average wind speed is less than 4.5 m/s which is considered as poor (Table 15).

### 11.9. Wind speed information for five cities in 2000

Of the five stations from which the data have been received; city of Marvast had the highest potential for wind energy with the mean speed of 3.90 m/s and 5.15 m/s at the heights of 10 m and 40 m, respectively. City of Marvast had the highest wind speed of 4.73 m/s in March, also the lowest wind speed of 3.08 m/s in November at 10 m elevation.

City of Yazd had the mean wind speed of 2.85 m/s at the height of 10 m and 5.24 m/s at the height of 40 m with the highest wind speed of 3.75 m/s in July and the lowest wind speed of 2.06 m/s in November at 10 m elevation.

With the mean wind speed of 1.55 m/s and 2.10 m/s at the height of 10 m and 40 m, respectively, city of Bafgh had the highest wind speed of 2.83 m/s in July, also the lowest wind speed of 0.77 m/s in November at 10 m elevation.

City of Tabas had the mean wind speed of 1.52 m/s at the height of 10 m, and 2.06 m/s at the height of 40 m with the highest wind speed of 3.39 m/s in July and the lowest wind speed of 0.26 m/s in December at 10 m height from ground level.

City of Rabat had the mean wind speed of 2.90 m/s at height of 10 m, and 3.57 m/s at 40 m elevation. Highest wind speed of 4.06 m/s occurs in July, and the lowest wind speed of 1.54 m/s in November at 10 m elevation (Table 16).

According to data for the year 2000, all the cities had the annual wind speed of less than 4.5 m/s which is not good value for wind turbine installation.

### 11.10. Wind speed information for five cities in 2001

According to Table 17, city of Marvast had the mean speed of 4.05 m/s and 5.35 m/s at the heights of 10 m and 40 m, respectively, having the higher wind energy potential than the other regions in province of Yazd in Iran. City of Tabas had the mean wind speed of 1.33 m/s at the height of 10 m, with very low wind energy potential. It is clear from data of Table 17 that all five cities had average annual wind speed of less than 4.5 m/s which is not in acceptable range for wind turbine installation. But it is possible to install small wind turbine for household purpose in harvest area.

### 11.11. Wind speed information for six cities in 2002

According to Table 18, city of Maybod had the mean speed of 4.17 m/s and 5.66 m/s at the heights of 10 m and 40 m, respectively, having the higher wind energy potential than the other regions in province of Yazd in Iran. City of Tabas had the mean wind speed of 1.24 m/s at the height of 10 m, again with very low wind energy potential. Also city of Marvast with 3.95 m/s wind speed along with city of Maybod are capable of harnessing wind for small turbines.

**Table 16**
Annual wind speed at different elevations for 2000.

| City | $V_{10}$ | $V_{20}$ | $V_{40}$ | $V_{max}$ | Direction |
|---|---|---|---|---|---|
| Yazd | 2.85 | 3.50 | 5.24 | 11.27 | 289.80 |
| Bafgh | 1.55 | 1.80 | 2.10 | 4.45 | 277.50 |
| Tabas | 1.52 | 1.77 | 2.06 | 10.20 | 247.50 |
| Marvast | 3.90 | 4.49 | 5.15 | 12.59 | 180.80 |
| Rabat | 2.90 | 3.22 | 3.57 | 9.25 | 169.20 |

**Table 17**
Annual wind speed at different elevations for 2001.

| City | $V_{10}$ | $V_{20}$ | $V_{40}$ | $V_{max}$ | Direction |
|---|---|---|---|---|---|
| Yazd | 3.01 | 3.69 | 5.63 | 11.69 | 283.33 |
| Bafgh | 1.74 | 2.03 | 2.36 | 5.22 | 265.83 |
| Tabas | 1.33 | 1.55 | 1.80 | 13.58 | 280.00 |
| Marvast | 4.05 | 4.66 | 5.35 | 14.48 | 195.00 |
| Rabat | 2.82 | 3.13 | 3.47 | 9.64 | 246.67 |

**Table 18**
Annual wind speed at different elevations for 2002.

| City | $V_{10}$ | $V_{20}$ | $V_{40}$ | $V_{max}$ | Direction |
|---|---|---|---|---|---|
| Yazd | 2.95 | 3.60 | 5.40 | 12.21 | 237.50 |
| Bafgh | 2.93 | 3.42 | 3.98 | 15.33 | 300.00 |
| Tabas | 1.24 | 1.45 | 1.69 | 10.28 | 252.50 |
| Marvast | 3.95 | 4.54 | 5.21 | 12.72 | 211.67 |
| Rabat | 3.03 | 3.36 | 3.72 | 9.98 | 200.00 |
| Maybod | 4.17 | 4.86 | 5.66 | 13.41 | 273.33 |

### 11.12. Wind speed information for 10 cities in 2003

According to the data obtained from 10 stations (Table 19), in year 2003, city of Aghda had the highest wind speed of 4.09 m/s at the height of 10 m, being regard as a good wind energy resource. According to Table 19, Marvast, Gariz, and Maybod had relatively proper wind speeds of close to 4 m/s which are good for small size wind turbines. Tabas had the wind speed of 1.24 m/s, having a low potential.

### 11.13. Wind speed information for eleven cities in 2004

In 2004, of the data (Table 20) obtained from 11 stations, city of Herat had the average annual wind speed of 6.66 m/s and 5.05 m/s at the height of 40 m and 10 m, respectively enjoying high wind energy potential. Marvast, Maybod, Aghda and Gariz can be in relatively proper condition. Tabas had the low wind energy potential with the speed of less than 1.01 m/s at 19 m elevation.

**Table 19**
Annual wind speed at different elevations for 2003.

| City | $V_{10}$ | $V_{20}$ | $V_{40}$ | $V_{max}$ | Direction |
|---|---|---|---|---|---|
| Yazd | 3.06 | 3.74 | 5.6 | 15.20 | 239.17 |
| Bafgh | 3.00 | 3.50 | 4.07 | 15.72 | 222.50 |
| Tabas | 1.24 | 1.45 | 1.69 | 10.45 | 311.67 |
| Marvast | 4.01 | 4.61 | 5.29 | 13.75 | 186.67 |
| Abarkouh | 3.79 | 4.41 | 5.14 | 16.1 | 230.83 |
| Rabat | 3.23 | 3.59 | 3.98 | 10.58 | 167.50 |
| Maybod | 3.82 | 4.46 | 5.19 | 14.05 | 280.83 |
| Mehriz | 3.54 | 4.12 | 4.80 | 10.37 | 221.50 |
| Aghda | 4.09 | 4.76 | 5.55 | 13.84 | 220.83 |
| Gariz | 3.89 | 4.67 | 5.59 | 11.61 | 234.17 |

**Table 20**
Annual wind speed at different elevations for 2004.

| City | $V_{10}$ | $V_{20}$ | $V_{40}$ | $V_{max}$ | Direction |
|---|---|---|---|---|---|
| Yazd | 2.91 | 3.56 | 5.35 | 13.19 | 250.00 |
| Bafgh | 2.71 | 3.77 | 3.69 | 12.60 | 257.50 |
| Tabas | 1.01 | 0.36 | 1.38 | 11.44 | 265.00 |
| Marvast | 3.91 | 4.48 | 5.16 | 15.85 | 202.50 |
| Abarkouh | 3.24 | 3.78 | 4.40 | 14.99 | 234.17 |
| Rabat | 3.33 | 3.70 | 4.10 | 10.88 | 174.17 |
| Maybod | 3.50 | 3.77 | 4.75 | 14.05 | 246.33 |
| Mehriz | 3.33 | 3.41 | 4.52 | 11.31 | 235.00 |
| Aghda | 3.84 | 3.72 | 5.21 | 16.15 | 195.83 |
| Herat | 5.05 | 5.80 | 6.66 | 15.25 | 239.17 |
| Gariz | 3.95 | 4.74 | 5.66 | 12.59 | 200.00 |

**Table 21**
Annual wind speed at different elevations for 2005.

| City | $V_{10}$ | $V_{20}$ | $V_{40}$ | $V_{max}$ | Direction |
|---|---|---|---|---|---|
| Yazd | 2.58 | 3.15 | 4.73 | 10.07 | 266.67 |
| Bafgh | 3.41 | 3.97 | 4.63 | 13.02 | 264.17 |
| Tabas | 2.16 | 2.52 | 2.93 | 11.91 | 229.17 |
| Marvast | 3.11 | 3.58 | 4.11 | 11.78 | 215.83 |
| Rabat | 4.00 | 4.45 | 4.93 | 12.42 | 190.83 |

### *11.14. Wind speed information for five cities in 2005*

According to Table 21, in 2005, Rabat had the highest wind energy potential with the average annual speed of 4.00 m/s at the height of 10 m.

City of Tabas had the speed of 2.93 m/s and 2.16 m/s at the heights of 40 m and 10 m, respectively, having low wind energy potential.

## 12. Analysis of the wind speed at different locations in province of Yazd City of Yazd

### *12.1. City of Yazd*

The city of Yazd is 1237.2 m above the sea level, located at 31–54 N and 17–54 E. According to the data collected during 13 years, the average wind speed is 2.58 m/s and 3.087 m/s at the heights of 10 m and 40 m, respectively per year.

The highest wind speed occurs in July with the average speed of 3.17 m/s and the lowest one happens in December with the average speed of 2.13 m/s at 10 m elevation.

The wind speed begins to rise in the mid-spring and reaches its peak in summer. The lowest wind speed occurs from mid-fall to mid-winter. Since the average wind speed is less than 4.5 m/s, it cannot be an ideal location for the installation of larger size wind turbines, but it is possible to install small size wind turbines for houses and also street lights (Figs. 13 and 14).

### *12.2. City of Bafgh*

Located at 31–36 N and 26–55 E, city of Bafgh is 9914 m above the sea level. According to the data collected from 1993 to 2005, Bafgh has the average wind speed of 2.22 m/s and 3.01 m/s at the heights of 10 m and 40 m, respectively per year. The highest wind speed occurs in July with the average speed of 2.94 m/s and the lowest wind speed happens in November with the speed of 1.72 m/s. Since the wind speed is less than 4.5 m/s per year, Bafgh cannot be an ideal location for installation of any wind turbines (Figs. 15 and 16).

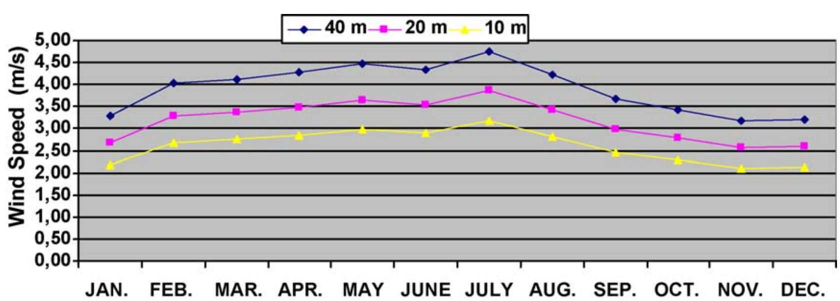


**Fig. 13.** . Average wind speed for different months from 1992 to 2005 for Yazd.

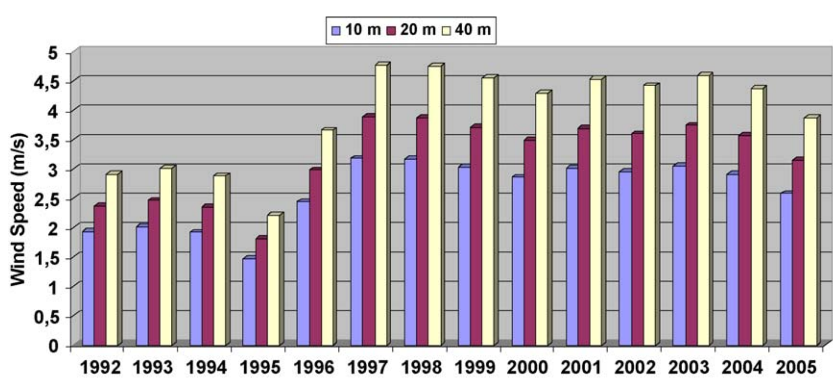


**Fig. 14.** Average annual wind speed from 1992 to 2005 for Yazd.

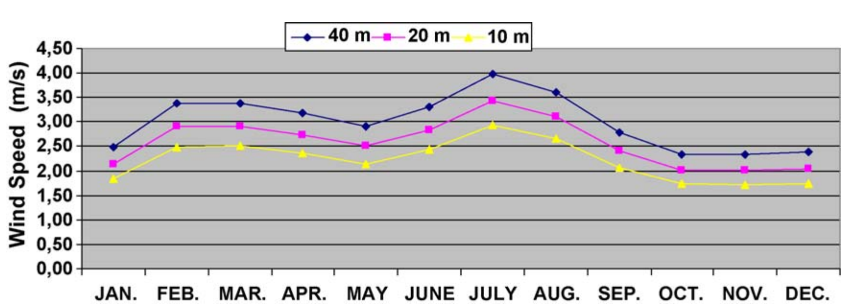


**Fig. 15.** Average wind speed for different months from 1993 to 2005 for Bafgh.

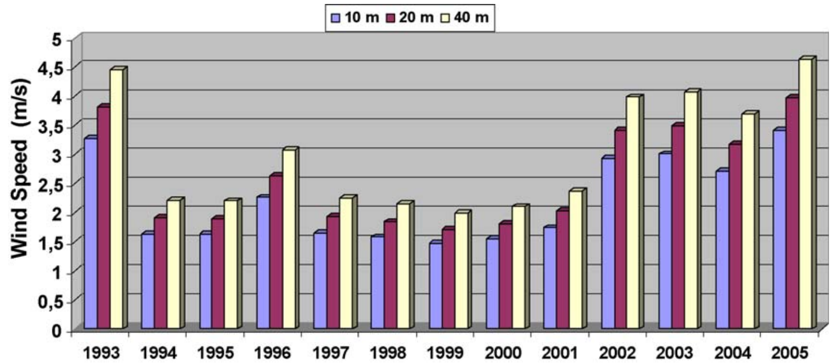


**Fig. 16.** Average annual wind speed from 1993 to 2005 for Bafgh.

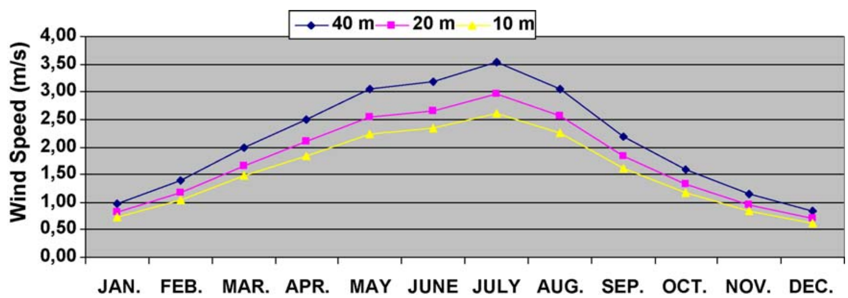


**Fig. 17.** Average wind speed for different months from 1992 to 2005 for Tabas.

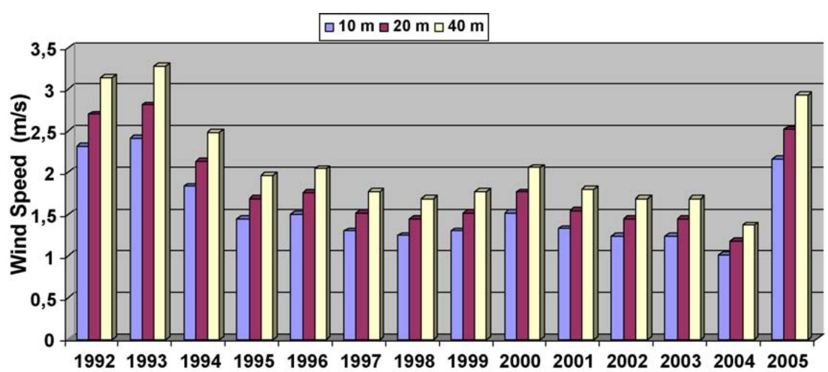


**Fig. 18.** Average annual wind speed from 1992 to 2005 for Tabas.

### *12.3. City of Tabas*

Located at 33–36 N and 55–56 E, city of Tabas is 711 m above the sea level. Tabas has the average wind speed of about 1.56 m/s and 2.12 m/s at the heights of 10 m and 40 m per year. The highest wind speed occurs in July with the mean speed of 2.61 m/s and the lowest wind speed happens in December with the speed of 0.62 m/s. Tabas has a very low energy potential so it cannot be an ideal location for installation of the big or small size wind turbines (Figs. 17 and 18).

### *12.4. City of Marvast*

City of Marvast is located at 30 N and 15–45 E, and is 1546.6 m above the sea level. According to the data collected from 1997 to

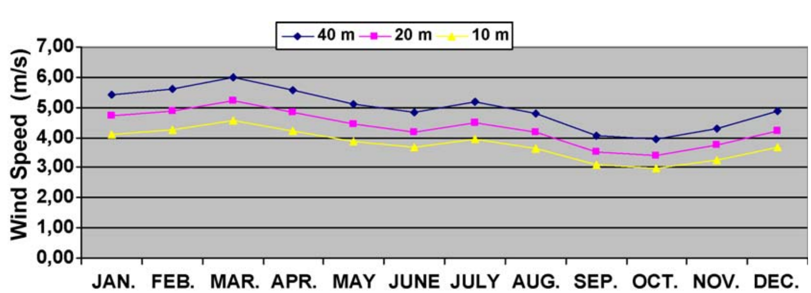


**Fig. 19.** Average wind speed for different months from 1997 to 2005 for Marvast.

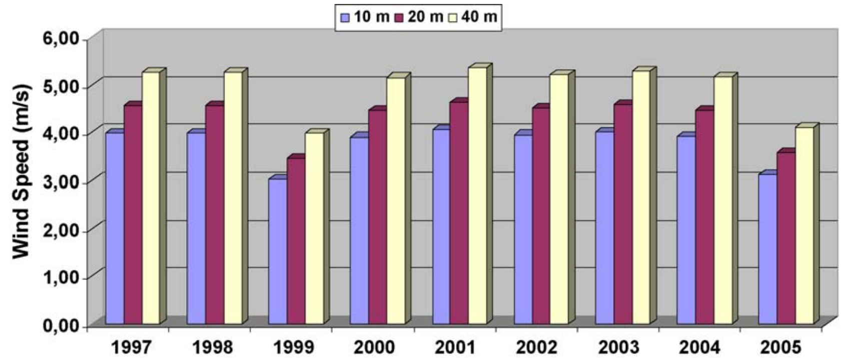


**Fig. 20.** Average annual wind speed from 1997 to 2005 for Marvast.

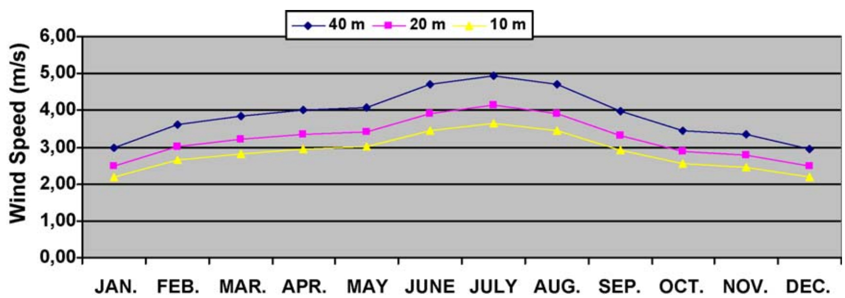


**Fig. 21.** Average wind speed for different months from 1992 to 2005 for Rabat.

2005, it has the average wind speed of 3.77 m/s and 4.97 m/s at the heights of 10 m and 40 m per year. The highest wind speed occurs in March with the average speed of 4.55 m/s and the lowest one happens in October with the mean speed of 2.98 m/s (Figs. 19 and 20).

So the highest and the lowest winds occur in the beginning of spring and in the middle of fall, respectively. It can be an ideal location for the installation of the small size wind turbine.

### 12.5. City of Rabat

Located at 2–30 N and 33–55 E, being 1188 m above the sea level, it has the average wind speed of about 2.86 m/s and 3.52 m/s at the heights of 10 m and 40 m, respectively per year. The highest wind speed occurs in July with the mean speed of 3.65 m/s and the lowest wind speed of 2.18 m/s in December, so the highest wind speed happens in the end of middle of summer, and the lowest one in the winter. It cannot be an ideal location for the installation of the large or small size wind turbines (Figs. 21 and 22).

### 12.6. City of Maybod

City of Maybod is located at 13–32 N and 53–58 E, and is 1108 m above the sea level. According to the data collected from 2002 to 2004, it has the average wind speed of 3.83 m/s and 5.20 m/s at the heights of 10 m and 40 m, respectively per year. The highest wind speed occurs in March with the mean of about 4.50 m/s and the lowest one in January with speed of 2.94 m/s. The highest wind speed happens at the end of the winter through the beginning of the summer and the lowest one in winter. Maybod is an ideal location for installation of the small wind Turbines. It should also be noted that there is a location near the city of Maybod which is called Maybod Wind Tunnel with six months of high wind which it covers an area of almost 15 km by 1 km. It is an amazing place and some wind pumps have been installed by water district authority, and agriculture organization of Yazd (Fig. 23).

### 12.7. City of Mehriz

Mehriz is located at 31–35 N and 26–54 E, being 1520 m above the sea level. It has the mean wind speed of 3.43 m/s and 4.67 m/s

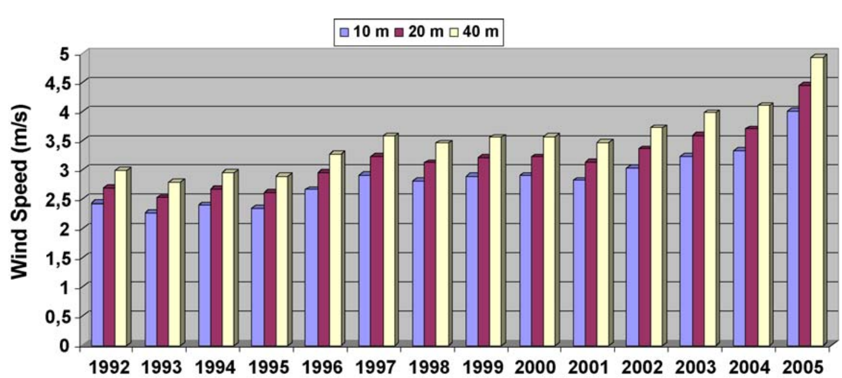


**Fig. 22.** Average annual wind speed from 1992 to 2005 for Rabat.

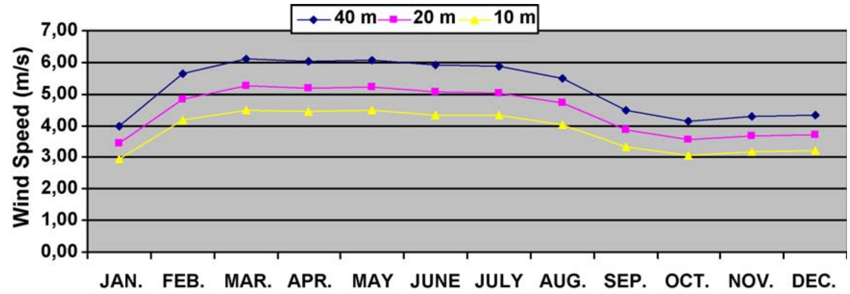


**Fig. 23.** Average wind speed for different months from 2002 to 2004 for Maybod.

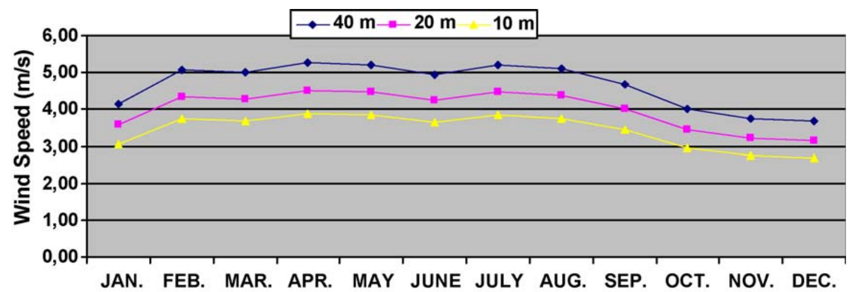


**Fig. 24.** Average wind speed for different months for Mehriz from 2003 to 2004.

at the heights of 10 m and 40 m, respectively per year. The highest wind speed occurs in April with the mean speed of 3.88 m/s and the lowest one in December with the speed of 2.70 m/s. So the highest wind speed happens on April and the lowest one at the end of fall through the winter. It cannot be an ideal location for installation of the commercial wind turbines, but small size turbines could be installed (Fig. 24).

### 12.8. City of Abarkouh

Abarkouh is located at 8–31 N and 17–53 E, being 1523.8 m above the sea level. It has the average wind speed of 3.51 m/s and 4.77 m/s at the heights of 10 m and 40 m, respectively per year. The highest wind speed occurs in February with the mean of 5.08 m/s and the lowest one in October, and November with the speed of 2.26 m/s. So the highest wind speed occurs in the mid-winter through the spring and the lowest one at the beginning of the fall through the mid-winter. It cannot be an ideal location for installation of the big size wind turbines, but it is one of the best locations in Yazd province (Fig. 25).

### 12.9. City of Aghda

Aghda is located at 26–32 N and 37–53 E, being 1150 m above the sea level. According to the data collected during two years, it has the average wind speed of 3.96 m/s and 5.38 m/s at the heights of 10 m and 40 m, respectively per year. The highest wind speed occurs in March with the mean of 4.73 m/s and the lowest one in December with the speed of 2.90 m/s at 10 m elevation. So the highest wind speed occurs at the end of winter through the mid-summer and the lowest one at beginning of the fall through the mid-winter. Aghda is an ideal location for installation of the small wind turbines (Fig. 26).

### 12.10. City of Gariz

Gariz is located at 18–31 N and 6–54 E, being 2100 m above the sea level. It has the mean wind speed of about 3.95 m/s and 5.65 m/s at the heights of 10 m and 40 m, respectively per year which was gathered for only one year. The highest wind speed occurs in May with the mean of about 4.83 m/s and the lowest one in October with the speed of 3.19 m/s. So the highest wind speed blows in spring and the lowest one at beginning of the fall through the mid-winter. Gariz can be an ideal location for installation of the small wind turbines. But since the above information is for only one year, more information is required for installation of wind turbines. As a matter of fact, it is an ideal location for small size turbines (Fig. 27).

### 12.11. City of Herat

Herat is located at 5–30 N and 4–54 E, being 1600 m above the sea level. According to the data collected during one year, it has the

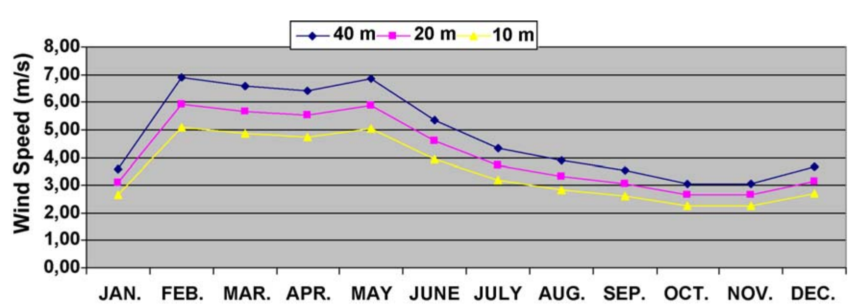


**Fig. 25.** Average wind speed for different months from 2003 to 2004 for Abarkouh.

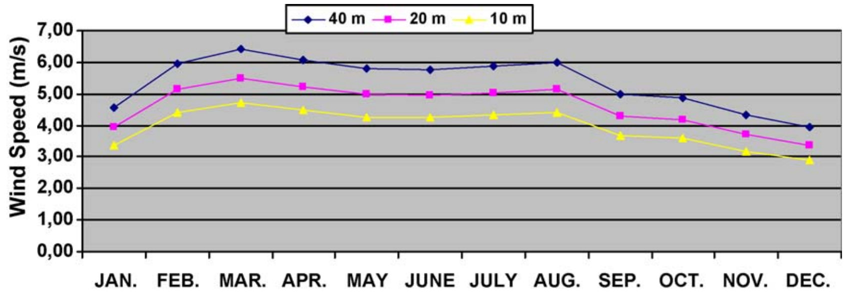


**Fig. 26.** Average wind speed for different months from 2003 to 2004 for Aghda.

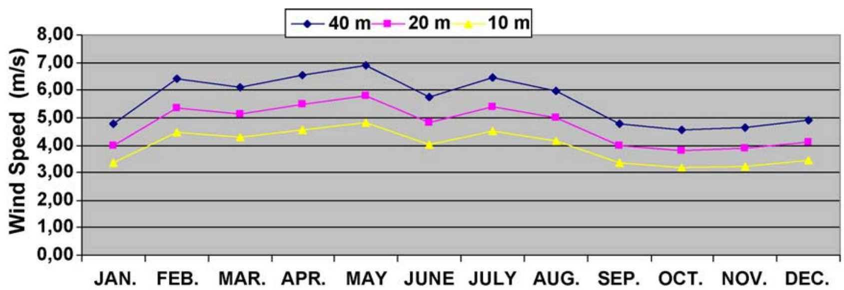


**Fig. 27.** Average wind speed for different months of 2004 for Gariz.

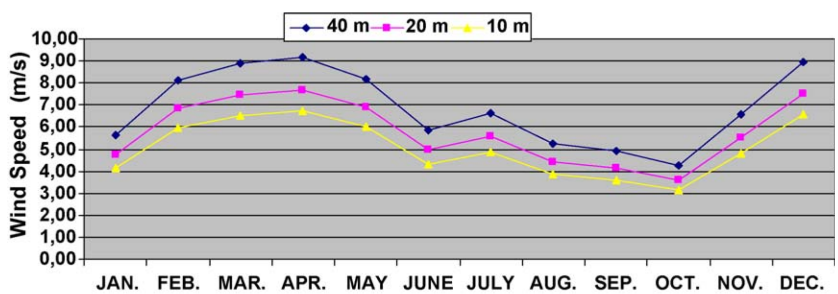


**Fig. 28.** Average wind speed for different months of 2004 for Herat.

average wind speed of about 5.05 m/s and 6.86 m/s at the heights of 10 m and 40 m per year. The highest wind speed occurs in April with the mean of about 6.73 m/s and the lowest one in October with the speed of 3.13 m/s. So the highest wind speed blows at the beginning of spring through the end of summer and the lowest one in fall. Herat can be the best location of all for the installation of the wind turbine. But since the information of wind speed for city of Herat is only for one year, so there should be more research about this area (Fig. 28).

## 13. Conclusion

Statistical detail study of wind speed at 10 m, 20 m and 40 m heights for eleven cities in province of Yazd in Iran is presented. It is expected that the work will be useful for studying the effectiveness and implementation of small wind turbines for water pumping and also will provide a strong base for harnessing wind in Yazd province. There are important justifications to be found for promoting different sources of renewable energy in Yazd such as wind, and solar. This paper utilized wind speed data over a period of almost 13 years between 1992 and 2005 from 11 stations, to assess the wind power potential at these sites. In this paper, the hourly measured wind speed data at 10 m, 20 m and 40 m height for Yazd province have been statically analyzed to determine the potential of wind power generation. Extrapolation of the 10 m data, using the Power Law, has been used to determine the wind data at heights of 20 m and 40 m. The results showed that most of the stations have annual average wind speed of less than 4.5 m/s which is considered as unacceptable for installation of the wind turbines. City of Herat has higher wind energy potential with annual wind speed average of 5.05 m/s and 6.86 m/s, respectively at height of 10 m, and 40 m above ground level (AGL). This sites is a good candidate for remote area wind energy applications. But some more information is required, because the collected data for Herat is only for 2004. Cities of Aghda with 3.96 m/s, Gariz with 3.95 m/s, and Maybod with 3.83 m/s annual wind speed average at height of 10 m above ground level are also able to harness wind by installing small wind turbines. Capital city of Yazd with annual average wind speed of 2.58 m/s, Marvast with 3.77 m/s, Rabat with 2.86 m/s, Mehriz with 3.43 m/s, and Abarghou with 3.51 m/s at 10 m elevation could be candidates for small wind turbines. The Tabas and Bafgh sites wind speed data indicated that the two sites have lower annual wind speed averages between 1.56 m/s and 2.22 m/s at 10 m height. The monthly and annual wind speeds at different heights have been studied to ensure optimum selection of wind turbine installation. Using wind turbine technology can be a suitable choice compared to other sources, but it should be noted that development of wind turbine in Iran is admirable and in the future many suitable areas would become the site for the small or big wind turbine farms.

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